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SHORT PAPERS ON GEOLOGIC SUBJECTS

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AREAL GEOLOGY OF PART OF CENTRAL EASTERN ILLINOIS*

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Bedrock outcrops are scarce in central-eastern Illinois, which is covered by glacial drift. Samples from wells in this area show that rock formations of Silurian, Devonian, Mississippian, and Pennsylvanian age underlie the glacial drift. Except in a few limited areas, the wells are widely scattered. In order to map the areal distribution of the systems beneath the drift, it is necessary (1) to reconstruct the topography of the bedrock surface on which the drift was deposited and (2) to determine the geologic structure which controls the intercepts of the systems with the bedrock surface. Previous areal maps of this area (Weller, 1945) have shown the general structure of the area, but little consideration was given to the variations in bedrock topography.

The bedrock topography of Illinois was mapped by Horberg (1950). In central-eastern Illinois, present topography (fig. 1) shows little relation to the bedrock topography (fig. 2), which was mapped almost entirely on the basis of well data. The major feature of the bedrock surface is the preglacial Mahomet (Teays) bedrock valley. It crosses the area from the southeast corner of Iroquois county westward across southern Ford and northern Champaign counties, and then trends southwest to central Piatt county, thence to the present Illinois River valley in Mason County. The Danville preglacial valley extends northward across Vermilion County to join the Mahomet valley. The Pesotum preglacial valley extends across Douglas and southern Champaign counties to join the Mahomet valley in Piatt County.

The topography has an areal relief of about 300 feet. It is drained by the Sangamon, Embarass, and Vermilion rivers. The drainage pattern is not related to the bedrock topography, which has about 400 feet of relief and is rougher than the present surface.

Because the top of the Devonian limestone is one of the most persistent subsurface horizons easily identified in samples from wells drilled in the area, it is used as the horizon for mapping the structure (fig. 3). The LaSalle anticlinal belt crosses central-eastern Illinois from north to south. It has a structural relief of at least 2,400 feet. The dip on the west side of the LaSalle anticlinal belt, is relatively steep toward Illinois basin whereas it is more gentle on the eastern side. The doming of the anticlinal belt brings to the bedrock surface formations that range in age from Silurian to Mississippian. To the east, the Oakland anticlinal belt lies almost parallel to the LaSalle anticlinal belt beyond which is the Marshall-Sidell syncline.

In constructing the geologic map, well records were considered the primary data. The structure and bed-

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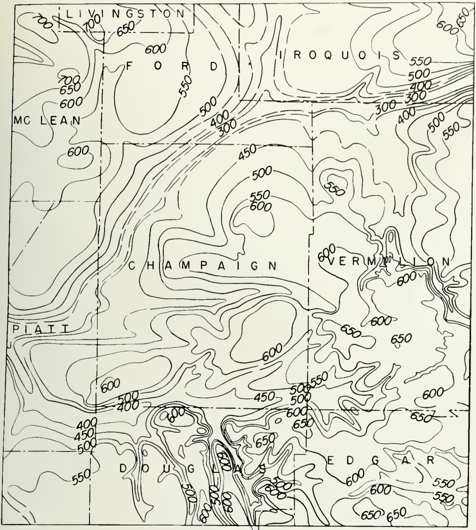
TOPOGRAPHY of PART of CENTRAL EASTERN ILLINOIS
Contour interval 50 feet; datum sea-level

Fig. 1

rock topography maps were used to control the trends of the boundaries and the distance which they were projected along the bedrock valleys.

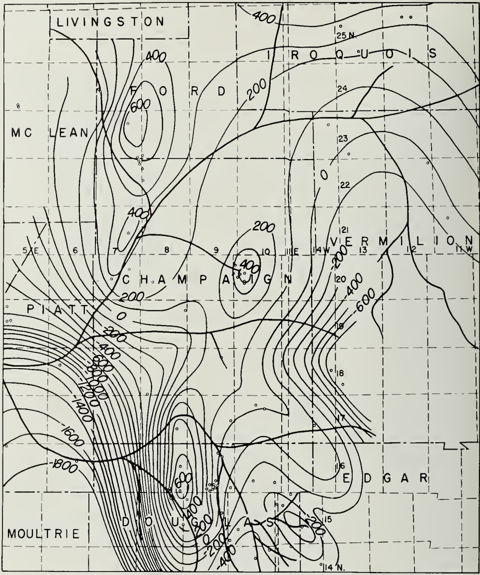
The influence of the Mahomet (Teays) bedrock valley is indicated on the areal geology map (fig. 4) by the northeastern and southwestern elongation of the Silurian and Devonian systems exposed on the bedrock surface of the Gibson City dome in northern Champaign and southern Ford counties. A tongue of Devonian and Mississippian rocks is also projected into the southeastern corner of Iroquois County where the Mahomet valley extends from Illinois into Indiana.



BEDROCK TOPOGRAPHY of PART of CENTRAL EASTERN ILLINOIS
(after Horberg)
Contour interval 50 feet; datum sea-level

FIG. 2

On the more steeply dipping west side of the LaSalle anticlinal belt—on the Tuscola dome in southern Champaign and northern Douglas counties—data from studies of wells indicate that Pennsylvanian strata overlapped the Mississippian formations to rest directly on Devonian strata; therefore no Mississippian formations are mapped at the bedrock surface exposed on the west side of the Tuscola dome. A similar overlap seems to exist for the Devonian exposures on the Gibson City dome in northern Champaign and southern Ford counties; hence Pennsyl-



STRUCTURE of TOP of DEVONIAN LIMESTONE and DRAINAGE PATTERN of the BEDROCK SURFACE

◦ Wells to bedrock — Drainage lines - Contour interval 100 feet; datum sea-level

Fig. 3

vanian strata are mapped as lying directly on the Devonian in this area. The Sellers dome on the Oakland anticlinal belt, in central Champaign County, slightly east of the main axis of the LaSalle anticlinal belt, brings Mississippian strata to the bedrock surface.

The New Albany shale is included in the Devonian system in drawing

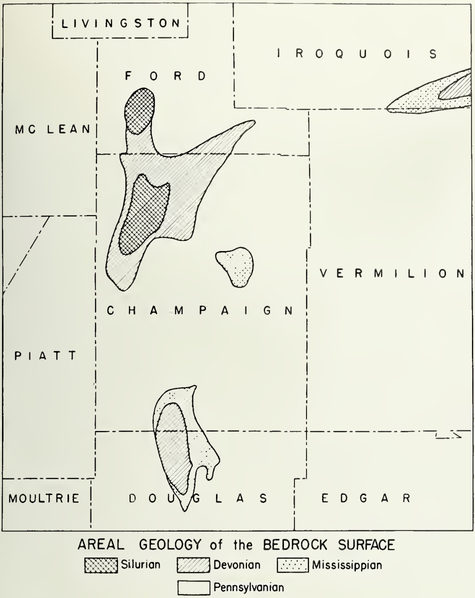


Fig. 4

the areal geologic map of the area. The areal pattern (fig. 4) shows the limits of the Silurian, Devonian, and Mississippian systems, none of which crop out at the surface of the described region. Pennsylvanian strata cover the rest of the area of the bedrock surface, and they crop out in southern Vermilion and northern Edgar counties.

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PROSPECTING FOR COMMERCIAL SAND AND GRAVEL USING ELECTRICAL EARTH RESISTIVITY, CLINTON COUNTY, ILLINOIS[*]

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Electrical earth-resistivity methods for locating deposits of water-bearing sand and gravel have been used by the Illinois State Geological Survey for many years. The methods used in interpreting resistivity data have been largely empirical but nevertheless very successful for locating large deposits of water-bearing sand and gravel suitable for municipal and industrial water supplies. These empirical interpretations have been based on methods outlined by O. H. Gish and W. J. Rooney[1] using the Gish-Rooney curve, the Moore cumulative curve outlined by R. Woodward Moore,[2] and the resistivity profile outlined by K. O. Emery.[3]

The sand and gravel deposits located by these empirical resistivity methods have usually been relatively large, fairly clean deposits associated with glacial till, made up largely of clays and silts. Resistivity of sand or gravel is generally 200 to 300 times as great as that of the surrounding glacial till, which permits successful use of empirical methods of interpretation. Experience has shown that, when the lith- contrast in resistivities, accurate interpretation is difficult.

In an attempt to interpret complex geological areas more accurately, the Division of Groundwater Geology and Geophysical Exploration of the Illinois State Geological Survey inaugurated a research program to investigate the application of other methods of analyzing resistivity data. The literature on interpretation of electrical earth resistivity data was studied intensively and a report was prepared outlining the methods advanced by G. F. Tagg,[4] William A. Longacre,[5] Sylvain J. Pirson,[6] Irwin Roman,[7] Robert J. Watson and James F. Johnson,[8] W. W. Wetzel and Howard V. McMurry,[9] R. Woodward Moore,[10] I. E. Rosenzweig,[11] and R. J. Wat- ology of an area does not give a sharp

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[1] Gish, O. H. and Rooney, W. J., Measurement of resistivity of large masses of undisturbed earth: Terr. Mag., vol. 30, pp. 161-188, 1925.

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[10] Moore, R. Woodward, An empirical method of interpretation of earth-resistivity measurements: AIME Trans. Geophysics, vol. 164, p. 197, 1945.

[11] Rosenzweig, I. E., A new method of depth determination in earth-resistivity measurements: AIME Geophysical Prospecting, vol. 138, pp. 408-417, 1940.

son.[12] The method described by Wetzel and McMurry seemed to be the most promising.

Locating deposits of sand or gravel for commercial use is one of the major problems that are often associated with a complex geologic situation. Such a problem arose when the Clinton County Highway Department requested information from the Survey on prospecting areas for sand and gravel to be used for road building. In order to locate areas worth testing by drilling, an electrical earth resistivity survey was conducted. The area investigated included Irishtown and Wheatfield townships, Clinton County, which lie between the Kaskaskia River on the east and Shoal Creek on the west, and which are bounded on the north by the Clinton-Bond county line. A few stations were also located in Wade township. The entire area was in townships 2 and 3 north, ranges 2 and 3 west.

The major portion of the area is relatively flat upland prairie that stands about 470 feet above sea level. The general flatness is relieved by morainic hills that rise sharply to a height of more than 40 feet and form impressive features of the landscape. There are many of these hills along the Clinton-Bond county line and in the northeast portion of Irishtown township around Keysport. The hills are of three distinct forms, rounded, elongated, and irregular. The principal drainage of the area is the Kaskaskia River and its tributaries, among which are Beaver Creek and Shoal Creek. On the whole the area between the Kaskaskia River and Beaver Creek is poorly drained. The gradient of the Kaskaskia River is about one foot per mile.

Several criteria governed the field work for the resistivity survey. Since the sand or gravel was to be used as road-building material, the deposits had to be at relatively shallow depths to be economically feasible to develop. Therefore, the investigation was limited to depths of less than fifty feet. As it seemed likely that the best deposits would be in the morainic hills, stations on and around the hills were located about a tenth of a mile apart. Stations on the flat prairie were located about two-tenths of a mile apart. They were generally placed along roads, but a few were located in fields (see fig. 1).

The data were plotted on 2 x 2 cycle logarithm paper and interpreted by superposing the curves obtained from field data over master curves as outlined by W. W. Wetzel and Howard V. McMurry.[13] This method applies to the three-layer case in which the thickness of the top layer is (h_1), the thickness of the second layer is (d), the thickness of the third layer is infinite, the depth from the surface to the top of the third layer is (h_2), and the resistivities of the layers are ρ_1, ρ_2, and ρ_3, respectively. The following values are determined from the master curves: (h_2), depth to top of third layer; (ρ_1), resistivity of top layer; (h_1:d), ratio of thickness of first and second layers.

The readings from each station were plotted, and an attempt was made to interpret each curve. How-

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[12] Watson, R. J., A contribution to the theory of the interpretation of resistivity measurements obtained from surface potential observations: AIME Geophysical Prospecting, vol. 110, pp. 201-232, 1934.

[13] Wetzel, W. W. and McMurry, H. V., op. cit.

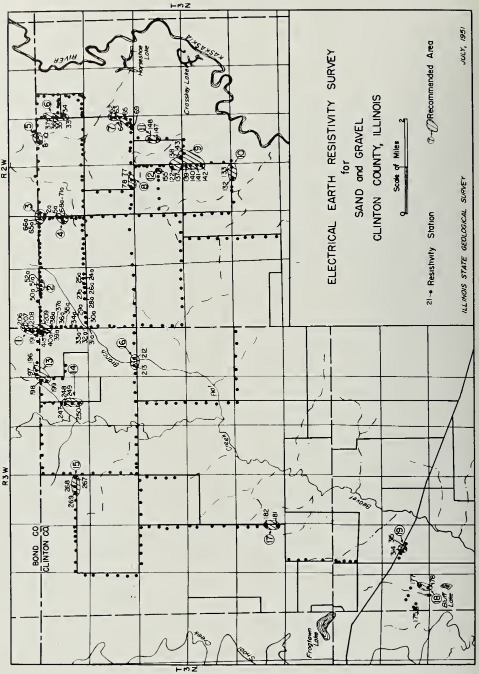
ELECTRICAL EARTH RESISTIVITY SURVEY
for
SAND and GRAVEL
CLINTON COUNTY, ILLINOIS
Scale of Miles
0
2
21 Resistivity Station
Recommended Area
ILLINOIS STATE GEOLOGICAL SURVEY
JULY, 1951
T3N
R2W
R3W
BOND CO
CLINTON CO
KASKASKIA RIVER
Horseshoe Lake
Crosskey Lake
Froglown Lake
Bluff Lake
Shoal Creek
Beaver Creek
Flat Creek
Branch

Fig. 1

ever, many of the curves did not lend themselves to very good interpretations because the plotted points did not conform to a typical three-layer situation. The stations that did lend themselves most readily to interpretations are listed in groups in table 1. The areas listed in table 1 were recommended for prospecting with particular emphasis on areas 1, 2, 7, 9, and 18.

The areas recommended for prospecting were selected on the basis of several considerations. The first consideration was that of the class of master curves to which the data conformed. The governing criterion was the ratio of resistivities. It was reasoned that, in this survey, sand or gravel deposits would be surrounded by glacial till with the resistivity of the till relatively low and the resistivity of the sand or gravel relatively high. The magnitude of the resistivity of the sand or gravel would depend upon the degree of silt and other impurities included. It was thought that a desirable curve would be one in which the ratio of resistivities ($\rho_1 : \rho_2 : \rho_3$) was in the order of 1:100:1.

The second consideration was to select areas in which resistivity stations close together fell into one class of master curves. It was felt that the more stations in a given area that had the same type of master curve, the greater was the possibility of finding a deposit large enough to be developed commercially.

The third consideration was that of the range and magnitude of the apparent resistivity readings (ρ_a) at a particular station. As clean sand or gravel should have a high resistivity, stations where the resistivity values ranged from low to relatively high readings were considered to be good possibilities. An example of this is station 39a in prospecting area 1, where resistivities ranged from 8400 ohm-centimeters to 40,000 ohm-centimeters (see table 1). Using the information in table 1, a Clinton County Highway Department crew test-drilled some of the recommended locations. A representative of the Illinois State Geological Survey accompanied the drilling crew and collected samples. The test-drilling was somewhat inadequate because the available equipment was only able to penetrate to 20 feet. Sixteen test holes were drilled and in 13 of the 16 there were good correlations between the actual records and the predictions based on resistivity interpretations. Table 2 shows the test hole data compared with the resistivity interpretations.

ANALYSIS OF DATA

In table 1 estimates of the thickness of the top layer (h_1) and the second layer (d) are given. These were computed algebraically from the information obtained from the master curves based on the contact depth (h_2). It can be seen in table 2 that the most accurately interpreted value was (h_2), the depth to the top of the third layer.

Station 39a.—The resistivity ratio here is $\rho_1 : \rho_2 : \rho_3 = 1:100:1$, which indicates the resistivity of the second layer to be relatively large. Resistivity readings (ρ_a) range from 8400 ohm-cms. to 40,000 ohm-cms. In this case there is a correlation between (h_1), estimated at 12 feet, and the first lithologic break, which the test hole showed to be at 14 feet. The interpretation of (h_2) is also believed to be valid as the total depth of the test hole is only 20 feet. The resistivity ratio is consistent with the

TABLE 1.—INTERPRETATION OF ELECTRICAL EARTH RESISTIVITY DATA IN AREAS RECOMMENDED FOR PROSPECTING FOR SAND OR GRAVEL

Area no.	*Station no.*	*Resistivity ratio* $\rho_1:\rho_2:\rho_3$	*Estimated contact depth* (h_2)	*Estimated overburden* (h_1)	*Estimated thickness of sand/gravel* (d)	*Range of resistivity readings* (ρ_a) ohm-cm
1	38a	1:10 :1	19	14	5	6900-14000
	39a	1:100:1	24	12	12	8400-40000
	40a	1:100:1	34	17	17	4300-17200
	41a	1:100:1	21	10	11	5000-31800
	209	1:10 :1	28	14	14	5000-15400
	208	1:10 :3	30	15	15	7100-22800
	206	1:10 :⅓	28	7	21	10100-31300
	191	1:100:1	11	8	3	7000-26500
2	50a	1:10 :1	13	3	10	3000-16700
	51a	1:10 :1	13	4	9	2700-16600
	52a	1:10 :⅓	27	7	20	3500-9400
3	65a	1:100:⅓	16	12	4	3900-15300
	66a	1:10 :3	9	6	3	4100-14500
	1a	1:10 :3	12	9	3	6300-19300
	2a	1:10 :1	21	15	6	4800-12800
	1	1:10 :3	13	7	6	3300-10000
4	5a	1:10 :⅓	20	10	10	5500-11100
	68a	1:10 :3	10	7	3	6500-20800
	69a	1:100:10	22	16	6	7300-27500
	70a	1:100:1	18	14	4	8600-26700
	71a	1:10 :⅓	13	7	6	4400-6800
5	8	1:10 :3	8	6	2	6600-16000
	9	1:10 :3	11	8	3	5700-20500
	10	1:10 :3	6	4	2	5000-19800
	11	1:10 :1/10	15	8	7	4500-8000
6	33	1:⅓ :3	31	8	23	11400-4000
	34	1:10 :3	19	14	5	6800-11000
	35	1:100:1/10	14	11	3	6400-21300
	36	1:10 :1	34	8	26	6600-21600
	37	1:10 :3	18	9	9	4000-13700
7	62	1: 3 :100	20	20	?	5000-25000
	63	1:100:1	33	16	17	7000-24000
	64	1:10 :100	15	11	4	3500-18000
	65	1:10 :3	13	7	6	3000-9200
	69	1:100:1	22	16	6	4000-12400
8	77	1:10 :3	8	6	2	5000-12800
	78	1:10 :1/10	30	15	15	3000-6000
9	142	1:10 :3	12	9	3	5000-16700
	141	1: 3 :10	9	6	3	4000-20000
	140	1:10 :1	20	10	10	4300-9600
	139	1:10 :1	15	10	5	4100:9900
	137	1:10 :⅓	27	13	14	5600-11900
	122	1:10 :⅓	25	12	13	3300-9200
	138	1:100:⅓	10	7	3	3900-15000
	143	1:1/9:∞	35	35	?	9400-1800

TABLE 1.—(CONTINUED)

Area no.	*Station no.*	*Resistivity ratio* $\rho_1:\rho_2:\rho_3$	*Estimated contact depth* (h_2)	*Estimated overburden* (h_1)	*Estimated thickness of sand/gravel* (d)	*Range of resistivity readings* (ρ_a) ohm-cm
10	132	1:1/10:100	16	16	?	5300-1500
	133	1:1/5.67:∞	8	8	?	10300-3900
11	147	1:1/10:3	10	10	?	5800-3100
	148	1:10 :1	25	12	13	5900-13200
12	155	1:10 :1	15	7	8	3800-10200
13	196	1:10 :3	12	9	3	3600-10500
	197	1:10 :3	10	7	3	4200-10700
	198	1:19 :2.11	31	15	16	2500-8000
	199	1:10 :1/10	21	15	6	1900-4300
14	247	1:10 :3	24	12	12	4700-13700
	248	1:100:1	16	12	4	4300-22000
	249	1: 3 :1	28	7	21	5000-10700
15	267	1:⅓:10	15	15	?	4300-6600
	269	1:⅓:1	15	15	?	7800-5300
16	212	1:100:⅓	14	10	4	1400-5000
	213	1:100:1	24	18	6	3000-6200
17	181	1:10 :3	17	8	9	2300-7800
	182	1:10 :3	10	7	3	2900-8000
18	175	1:10:1/100	17	8	9	2500-5500
	177	1:10:1	16	4	12	3000-11200
	178	1: 3:10	12	6	6	3300-14300
19	314	1:100:1	7	5	2	4400-15900
	315	1:10 :1/10	12	6	6	7000-16700

lithology because the clean, fine sand below 14 feet would have a high resistivity as compared to the resistivity of silty clay above 14 feet.

Station 208.—The resistivity ratio of 1:10:3 indicates that the second layer might be expected to be sand or gravel that is slightly more impure than the second layer material at station 39a. The relative resistivity (3) of the third layer indicates that the resistivity of the top layer is probably lower, and that of the second layer higher. Therefore, the material of the third layer probably has more silt, clay, or impurities than the second layer. This is partially borne out by the test hole logs which show a lithologic break at 14 feet, the top of the second layer. This is consistent with theory, in that, beginning at 14 feet, the stratum changes to a cleaner gravel which has a much higher resistivity than the clayey layer above it. The fairly high resistivity readings, ranging from 7,100 to 22,800 ohm-cms., indicate the possibility of sand or gravel.

Station 206.—The resistivity ratio of 1:10:⅓ implies that the second layer is composed of fairly clean sand or gravel, that the top layer possibly contains some sand or gravel, and that the bottom layer is composed of silty or clayey material. The high resistivity readings, from 10,100 to 31,300 ohm-cms., also imply good sand and gravel possibilities. The first 20 feet tested shows clean gravel with pebbles up to two inches in diameter. It is felt that 28 feet as the thickness of the top layer is a good interpretation, although the test hole only went down 20 feet.

TABLE 2.—LOGS OF TEST HOLES AND COMPARISON OF EARTH RESISTIVITY INTERPRETATIONS WITH ACTUAL CONDITIONS

Area no.	*Station no.*	*Test hole logs*		*Resistivity ratio* $\rho_1:\rho_2:\rho_3$	*Estimated contact depth* (h_2)	*Estimated overburden* (h_1)	*Estimated thickness of sand or gravel* (d)
		Depth (ft.)	*Material*				
1	39a	0-14	Clay, silty and pebbly, tough, yellow-brown	1:100:1	24*	12*	12
		14-20	Sand, clean, fine to medium, reddish				
	208	0-8	Silt, clayey, sandy, pebbly, reddish-brown	1:10:3	30	15*	15
		8-14	Gravel, slightly clayey and sandy, pebbles up to ¾-inch size				
		14-20	Same, less clayey				
	206	0-20	Fairly clean gravel up to 2-inch pebbles	1:10:⅓	28*	7	21
	191	0-12	Silt, sandy, clayey, pebbly, yellowish brown	1:100:1	11*	8	3
		12-16	Same, more sandy, darker				
		16-20	Gravel, slightly sandy and silty. Pebbles up to ¾-inch size				
2	52a	0-15	Silt, clayey, slight sand and pebbles, reddish-brown	1:10:1	13*	3	10
		15-20	Clay, very gravelly, reddish-brown				
4	5a	0-18	Silt, sandy, pebbly, dry, reddish-brown, gravel at base	1:10:⅓	20*	10	10
		18-20	Sand, clean, fine, reddish-brown				
	68a	0-12	Silt, slightly sandy, reddish-brown	1:10:3	10*	7	3
		12-20	Clayey, sandy, pebbly, yellow-brown				

* Predicted depths that are within two feet of the test hole data.

TABLE 2.—(CONTINUED)

Area no.	*Station no.*	*Test hole logs*		*Resistivity ratio* $\rho_1:\rho_2:\rho_3$	*Estimated contact depth* (h_2)	*Estimated overburden* (h_1)	*Estimated thickness of sand or gravel* (d)
		Depth (ft.)	*Material*				
6	35	0-12 12-14 14-20	Silt, sandy, clayey, pebbly, yellow-brown Clean sand, reddish brown Clay, tough, silty, pebbly	1:100:1/10	14*	11*	3*
	36	0-12 12-20	Silt, slightly sandy and pebbly, light brown Silt, sandy, with gray sheets, yellowish gray at bottom.	1:10:1	34	8	26
7	65	0-10 10-20	Silt, sandy, pebbly clayey, reddish-brown Silt, very sandy	1:10:3	13*	7	6
9	140	0-12 12-20	Sand, very fine, silty clayey yellowish-brown Sand, very fine, clean darker brown	1:10:1	20	10*	10
10	Btwn. 132& 133	0-18 18-20	Till, very pebbly, yellowish-brown Till less pebbly, more clayey	1:1/10:100	16*	16	?
18	175	0-16 16-20	Silt, sandy, clayey, grayish brown Till, very pebbly, reddish brown	1:10:1/100	17*	8	9
	177	0-17 17-20	Sand, silty, clayey, slightly pebbly, reddish brown Sand, very fine and clean	1:10:1	16*	4	12
	178	0-10 10-18 18-20	Silt, sandy, clayey, grayish brown Silt, same pebbly Sand, fine, silty, clayey, reddish brown	1:3:10	12*	6	6
19	315	0-10 10-20	Sand, fine, slightly clayey and silty, reddish brown Sand, finer, less clayey and silty	1:10:1/10	12*	6	6

Station 191.—The resistivity ratio of 1:100:1 implies that the top and bottom layers are composed of silty, clayey material and the second layer of fairly clean sand or gravel. The moderately high resistivity readings, ranging from 7,000 to 26,500 ohm-cms., indicate good sand or gravel possibilities. The interpretation shows a break at 11 feet and the test-hole log a break at 12 feet from silty, clayey material to sandier material. It appears here, as well as in most of the remaining stations, that the most significant value that can be determined is (h_2), the depth of the contact between sand or gravel of the second layer and silty-clayey material below. The (h_1) and (d) values do not seem to be valid.

Station 52a.—The resistivity ratio of 1:10:1 implies that the top and bottom layers are composed of silty-clayey material and that the second layer is slightly dirty sand or gravel. The resistivity readings of 3,000 to 16,700 ohm-cms. may be considered medium. The contact depth (h_2) was interpreted to be 13 feet, comparing favorably with the test-hole log which indicates a lithologic break, at 15 feet, from silty clayey sand to a very gravelly clay.

Station 5a.—The resistivity ratio of 1:10:⅓ implies that the top layer is very dirty sand containing considerable silt and clay grading into the cleaner sand or gravel of the second layer. The third layer is principally silt and clay. The interpretation of (h_2) was 20 feet and compares favorably with the test-hole log which shows a break, at 18-20 feet, from sandy silt to a clean, fine, reddish brown sand. The resistivity readings range from 5,500 to 11,100 ohm-cms.

Station 68a.—The resistivity ratio of 1:10:3 implies a top layer of silty-clayey material and a second layer of fairly clean sand or gravel grading into a third layer of dirty sand or gravel. The resistivity readings are fairly high, ranging from 6,500 to 20,800 ohm-cms. The contact depth (h_2) of 10 feet compares favorably with the test-hole log, which shows a break, at 12 feet, from slightly sandy silt to a clayey, pebbly, yellow-brown sand.

Station 35.—The resistivity ratio of 1:100:1/10 implies a somewhat sandy top layer with a second layer of very clean sand or gravel and a very clayey bottom layer. The resistivity readings have a fairly high range, from 6,400 to 21,300 ohm-cms., and indicate good sand or gravel. The interpreted thickness of 11 feet for (h_1) compares with the test-hole log which shows a lithologic break at 12 feet from a sandy silt to a clean reddish-brown sand. The contact depth (h_2) of 14 feet is also consistent with the test-hole log which shows a lithologic break, at 14 feet, from a clean reddish-brown sand to a tough, silty clay. The theoretical interpretation seems to conform almost exactly to the actual conditions.

Station 36.—The resistivity ratio of 1:10:1 implies that the top layer and the bottom layer are composed of silty clay and that the second layer is fairly clean sand or gravel. The resistivity readings have a fairly high range, 6,600 to 21,600 omh-cms., indicating fairly good sand or gravel. Not much can be said about the validity of the interpretation since the test-hole was only 20 feet deep and the interpreted contact depth (h_2) was estimated to be at 34 feet. However, the (h_1) of 8 feet is reasonably close to the first lithologic break, indicated at 12 feet in the test-hole log.

Station 65.—The resistivity ratio of 1:10:3 implies a top layer of silty-clayey material, with a second layer of fairly clean sand or gravel grading into a third layer of rather dirty sand or gravel. The resistivity readings, 3,000 to 9,200 ohm-cms., are not very high and indicate a sand or gravel that is not too clean. The contact depth (h_2) of 13 feet corresponds rather favorably to the test-hole log, in which there is a lithologic break, indicated at 10 feet, from a reddish-brown slightly sandy silt to a very sandy silt.

Station 140.—The resistivity ratio of 1:10:1 implies that the top layer and the bottom layer are composed of silty clay and that the second layer is a fairly clean sand or gravel. The resistivity readings, 4,300 to 9,600 ohm-cms., are not very high and indicate a sand or gravel that is not too clean. There does not seem to be any correlation between the contact depth (h_2) and the test-hole log. There might be correlation if there is a lithologic change at 20 feet, but without drilling a deeper hole there is no way of determining it. However, the (h_1) depth of 10 feet does correlate fairly well with the lithologic break at 12 feet in the test-hole log, where the material changes from a fine silty sand to a fine clean sand.

Station 132.—The resistivity ratio of 1:1/10:100 implies that the second layer, composed of a silty-clayey material having a low resistivity, is overlain by a material of greater resistivity such as sandy or pebbly till. The bottom layer, having a relative resistivity of 100, should be composed of fairly clean sand or gravel. The resistivity readings range from 5,300 to 1,500 ohm-cms. and then go back up to 5,000 ohm-cms. The reading is not very high and seems to contradict the statement made above that clean sand or gravel might be expected. On the basis of low resistivity readings the possibility of finding good sand or gravel is rather remote. Nevertheless the contact depth (h_2) of 16 feet compares favorably with the lithologic break, indicated in the test-hole log at 18 feet, where the material changes from very pebbly till to more clayey till.

Station 175.—The resistivity ratio of 1:10:1/100 implies that the second layer is composed of fairly clean sand or gravel, the top layer has some sand, and the bottom layer is tough and clayey. The resistivity readings, 2,500 to 5,500 ohm-cms., are rather low and do not indicate good sand and gravel. The contact depth (h_2) of 17 feet compares favorably with the lithologic break, indicated in the test-hole log at 16 feet, where the material changes from a sandy silt to a very pebbly till.

Station 177.—The resistivity ratio of 1:10:1 implies that the second layer is composed of fairly clean sand or gravel and the top and bottom layers are composed of silty clay. The resistivity readings, 3,000 to 11,200 ohm-cms., may be considered medium and indicate fairly good sand or gravel. The contact depth (h_2) of 16 feet compares favorably with the lithologic break, indicated in the test-hole log at 17 feet, where the material changes from a silty-clayey sand to a very fine and clean sand.

Station 178.—The resistivity ratio of 1:3:10 implies that the top layer is composed of silty-clayey material grading into a second layer of dirty sand or gravel, and the third layer is fairly clean sand or gravel. The resistivity readings, 3,300 to 14,300 ohm-cms., may be considered medium and indicate fairly good sand or gravel. The contact depth (h_2) of 12 feet compares favorably with the lithologic break, indicated in the test-hole log at 10 feet, where the material changes from a sandy-clayey silt to a pebbly silt.

Station 315.—The resistivity ratio of 1:10:1/10 implies that the second layer is composed of fairly clean sand or gravel, the top layer is somewhat sandy, and the bottom layer is silty and clayey. The resistivity readings, 7,000 to 16,700 ohm-cms., may be considered medium and indicate fairly good sand or gravel. The contact depth (h_2) of 12 feet compares favorably with the lithologic break, indicated in the test-hole log at 10 feet, changing from a slightly silty-clayey reddish-brown sand to a cleaner, finer sand.

SUMMARY

The methods of interpreting the resistivity data, as outlined by W. W. Wetzel and Howard V. McMurry, seem to give adequate results when searching for commercial sand or gravel deposits to be used for road-building and other purposes. The areas for best prospecting are those whose resistivity data conform to master curves having a resistivity ratio of 1:100:1. This plus high apparent resistivity readings are the two governing factors in recommending possible prospecting areas for deposits of sand or gravel.

The most consistently correctly interpreted value was depth to the top of the third layer (h_2). In 13 out of the 16 locations tested there was a definite correlation between the analysis of the test-hole logs and the resistivity interpretations. This has been referred to as the contact depth because it is the depth to the contact between the sand or gravel layer and the till layer. The sand or gravel may be the upper layer or the lower layer, but the fact that the contact depth was determinable is significant.

In several locations there was also a correlation between the interpreted thickness of the top layer (h_1) and the thickness of the second layer (d).

It is felt that where there was no apparent correlation, a detailed sampling procedure and microscopic sample study would reveal evidence supporting the interpretations by indicating lithologic breaks which would correspond to the electrical breaks shown by the interpreted resistivity data.

Test drilling bore out the prediction that Area 1 was the best area for sand or gravel deposits. It was predicted that Area 2 was a good prospecting area, and this also was borne out by test drilling in the southern part of the area. It was the deposit in Area 2 from which the Clinton County Highway Department obtained the sand and gravel for road building. Several other areas show good commercial possibilities, but leasing arrangements and other factors prevent their development at the present time.

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CERAMIC MATERIALS FROM MAGNESIUM-TREATED CLAYS*

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Thermal expansion characteristics of the crystalline and glassy constituents of ceramic materials are important in determining their physical behavior when the ceramics are placed in service. Refractory materials sometimes fail, largely because stresses derived from differential thermal expansion of their mineral constituents cause ruptures. Cordierite is a magnesium aluminum silicate mineral which has a very low coefficient of thermal expansion. Thus a cordierite body should find wide use in ceramics.

When kaolinite is treated with various magnesium compounds, numerous high-temperature phases develop, depending upon the conditions of treatment and firing. It is believed that the formation of a high-temperature phase can be facilitated if the final crystalline structure is derived from regrouped crystalline units which in turn were derived at a lower temperature from a third crystalline material. For example, in the development of cordierite from magnesium-treated kaolinites, a uniquely crystalline metakaolin phase results following dehydration at 600°C. This combines with Mg0 at 1000°C. to form spinel. With further increase in temperature spinel combines with cristobalite to give cordierite.

It is not necessary to postulate that at any stage in this sequence the crystalline components were broken down into amorphous constituents which recombined to give the subsequent crystalline phase. Thus the energy requirements in going from one crystalline phase to another, with only moderate shifts in the atomic network, should be appreciably less than if the starting materials were merely mixtures of metallic oxides and hydroxides in the proper proportions to give the desired product. It seemed that cordierite bodies could be produced at lower temperatures if the starting materials were crystalline components such as clay materials.

The high-temperature phases from a variety of kaolinitic clays treated with numerous compounds of magnesium were investigated, chiefly by means of X-ray diffraction. Those formed from mixtures of $MgCO_3$ and a relatively pure kaolinite from Anna, Illinois, are representative and will be discussed here.

Test pieces, 1″ x 1″ x 3″, prepared from mixtures of kaolin and $MgCO_3$ equivalent to 6 and 12 percent MgO, were fired to 1000°, 1100°, 1150°, and 1200°C. The high-temperature phases identified are summarized in table 1. Examination of these data brings out several relationships which seem to indicate something of the effect of various factors on formation of cordierite.

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* This paper was presented at the 1952 meeting. It is published with permission of the Chief, Illinois State Geological Survey.

TABLE 1.—HIGH TEMPERATURE PHASES IDENTIFIED BY X-RAY DIFFRACTION
Anna Kaolin-MgCO$_3$ (equivalent to 12 percent MgO)

	Cord.	*Mullite*	*Crist.*	*Spinel*	*B-qtz.*	*Minor*
1200°C......	VS*		W			
1150°C......	S		M	?		
1100°C......	MS		S	W		
1000°C......				M	S	Periclase ? Forsterite ?
	Anna Kaolin-MgCO$_3$ (equivalent to 6 percent MgO)					
1200°C.	M	M	S			
1100°C.	MW	M	VS	W		
1000°C.				M		"Gamma alumina" Periclase ?

1. Maximum cordierite is produced at 1200°C. with the addition of MgCO$_3$ in amounts equivalent to 12 percent MgO, with the development of no other aluminum or magnesium phases and with minor amounts of cristobalite.

2. Comparison of samples fired to 1200°C. and containing 6 and 12 percent MgO shows that when the MgO addition is reduced, mullite forms at the expense of cordierite, and cristobalite appears in greater amounts. Raw Anna kaolin containing no MgO fires to mullite and cristobalite only. It would seem that in the magnesium-treated clay, at high temperatures, cordierite and mullite both compete for the alumina constituent, the cordierite taking all the MgO it can utilize. Any alumina left goes into the formation of mullite. If the Al$_2$O$_3$ to MgO ratio approximates that of theoretical cordierite, alumina and magnesia are completely used up, with none available for the formation of mullite. This appears to be what happens when the Anna kaolin-MgCO$_3$ mixture (12 percent) is fired to 1200°C., as such a mixture upon dehydration has a chemical composition approximating that of theoretical cordierite (table 2).

3. The decrease in cristobalite which accompanies the increase in cordierite as more magnesium is added to the system suggests that cristobalite is used up in the development of cordierite.

4. Comparison of phases developed at various firing temperatures shows an increase in cordierite with increasing temperature, accompanied by a decrease in cristobalite. The MgO is tied up in phases other than cordierite at the lower temperatures. At 1000° and 1100°C. the phase is spinel.

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* VS = Very strong.
S = Strong.
MS = Moderately strong.
M = Moderate.
MW = Moderately weak.
W = Weak.

TABLE 2.—CHEMICAL COMPOSITIONS

	Anna Kaolin 12% MgO (Percent)	*Theoretical Cordierite (Percent)*
SiO_2	49.8	51.4
Al_2O_3	36.4	34.9
MgO	13.8	13.7

Thus the following sequence of events leading to the development of cordierite is suggested. When kaolin is treated with the equivalent of 12-percent MgO (sufficient to give a total chemical composition approximating theoretical cordierite), magnesium and aluminum are tied up in a spinel phase at 1000°C. As the temperature is elevated, cristobalite develops and the spinel becomes unstable, its aluminum-magnesium components combining with cristobalite to form ever-increasing amounts of cordierite. As the temperature increases cordierite continues to increase at the expense of spinel and cristobalite until ultimately at 1200°C. only cordierite and minor amounts of cristobalite are present.

When lesser amounts of MgO are added to the clay, this sequence is modified. At 1000°C. the magnesium is tied up in a poor spinel phase and the alumina in another poorly crystalline phase, probably gamma alumina. As the temperature is raised, the spinel becomes unstable, cristobalite forms, and the two start combining to give cordierite. The gamma alumina is used up in the formation of mullite. As the temperature is raised still higher, more cordierite is formed until at 1200°C. cordierite, mullite, and cristobalite remain.

Thus by varying the treatment of kaolinitic clays with magnesium, a variety of products can be obtained which contain various relative proportions of cordierite, mullite, and cristobalite. Likewise, clays of differing composition show differences in the amounts of high-temperature phases formed. Bodies high in cordierite can be made from common fireclays, which are dominantly kaolinitic but contain appreciable amounts of micaceous clay minerals and quartz. A wide variety of ceramic materials can therefore be developed which exhibit a diversity of properties. Samples containing cordierite as the major constituent are denser and exhibit considerably greater resistance to thermal shock than their non-magnesium-treated equivalents. Their refractoriness is diminished somewhat as MgO is added so that consideration must be given to choosing that property which is most important for each application.

This preliminary laboratory study of such materials can serve as a point of departure for large-scale studies in evaluation of cordierite bodies for commercial use.

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